The Wide-Field Imaging Interferometry Testbed

Xiaolei Zhang [1,2], William C. Danchi [2], David Leisawitz [2], Douglas B.Leviton [2],
Richard G. Lyon[2], Anthony J. Martino [2], and John C. Mather [2] Lee G. Mundy[3],
[1] Raytheon ITSS, [2] NASA Goddard Space Flight Center, [3] U. Maryland

Abstract

The Wide Field Imaging Interferometry Testbed WIIT will be used to support design studies for NASA's future space interferometry missions, in particular the SPIRIT and SPECS far infrared/submillimeter interferometers. WIIT operates at optical wavelengths and uses Michelson beam combination to achieve both wide field imaging and high resolution spectroscopy. It will be used chiefly to test the feasibility of using a large format detector array at the image plane of the sky to obtain wide field interferometry images through mosaicing techniques. In this setup each detector pixel records interferograms corresponding to averaging a particular pointing range on the sky as the optical path length is scanned and as the baseline separation and orientation are varied. The final image is constructed through spatial and spectral Fourier transforms of the recorded interferograms for each pixel, followed by a mosaic/joint deconvolution procedure of all the pixels. In this manner the image within the pointing range of each detector pixel is further resolved to an angular resolution corresponding to the maximum baseline separation for fringe measurements, and the total field coverage is determined by the number of detector pixels.

Motivation

The proposed Submillimeter Probe of the Evolution of Cosmic Structure SPECS and SPace InfraRed Interferometric Telescope SPIRIT missions are intended to make sensitive, high angular resolution observations of the far IR universe, and to study how the first galaxies and structures formed and evolved. Ideally, we would like to obtain images in the far infrared covering the same spatial extent - several arcminutes and with the same angular resolution - tens of milliarcseconds as the Hubble Deep Fields. This corresponds to roughly , x , resolution elements per image. Furthermore, to support high spatial resolution interferometry and to study line emissions from galaxies, we will need spectral resolution capability on the order of - , .

The coming of age of large format, background limited far infrared detector arrays calls for an exploration of the interferometer configurations that are best coupled to the characteristics of the detectors for acquiring wide field, high spatial and spectral resolution images. The SPECS and SPIRIT instruments, as currently envisioned, are both Michelson spatial spectral interferometers with or collector mirrors surrounding a central hub, and are capable of varying baselines so as to achieve full spatial frequency coverage. In order to establish the feasibility of using this configuration to achieve high fidelity wide field imaging, a laboratory testbed is being developed at NASA's Goddard Space Flight Center. This testbed is a scaled down version of SPECS, operating at optical wavelengths, and using the same kind of detection scheme as will be used for the space interferometers.

Objectives

. To establish the feasibility of the basic design configuration. We have chosen to use a pupil plane beam combination, image plane detection scheme, coupled with the mosaicing techniques for image analysis. This is a novel design concept for using the Michelson interferometer to do wide field imaging. The validity of this approach must be demonstrated.

. To study the optical performance of the design. The optics needs to be either aberration free both on and off axis over a wide field of view, or else an effective aberration compensation scheme needs to be devised in the optical setup or in the data reduction procedure.

. To study the many technical issues of data acquisition such as metrology, absolute phase reference, long stroke delay and on the fly data taking. Effective calibration of the data also needs to be investigated.

. To explore the imaging performance of various data analysis algorithms, especially the mosaic image reconstruction and joint deconvolution procedures developed by the radio astronomy community over the past decades.

. To study the effective management of the large amount of data obtained by the wide field, high resolution Michelson spatial and spectral interferometer, and to compare the efficiency of various data analysis algorithms.

. To explore other issues related to the design studies of the far IR missions, including the development of efficient and effective procedures for pointing and baseline determination, fringe acquisition and tracking, as well as other instrument calibration issues.

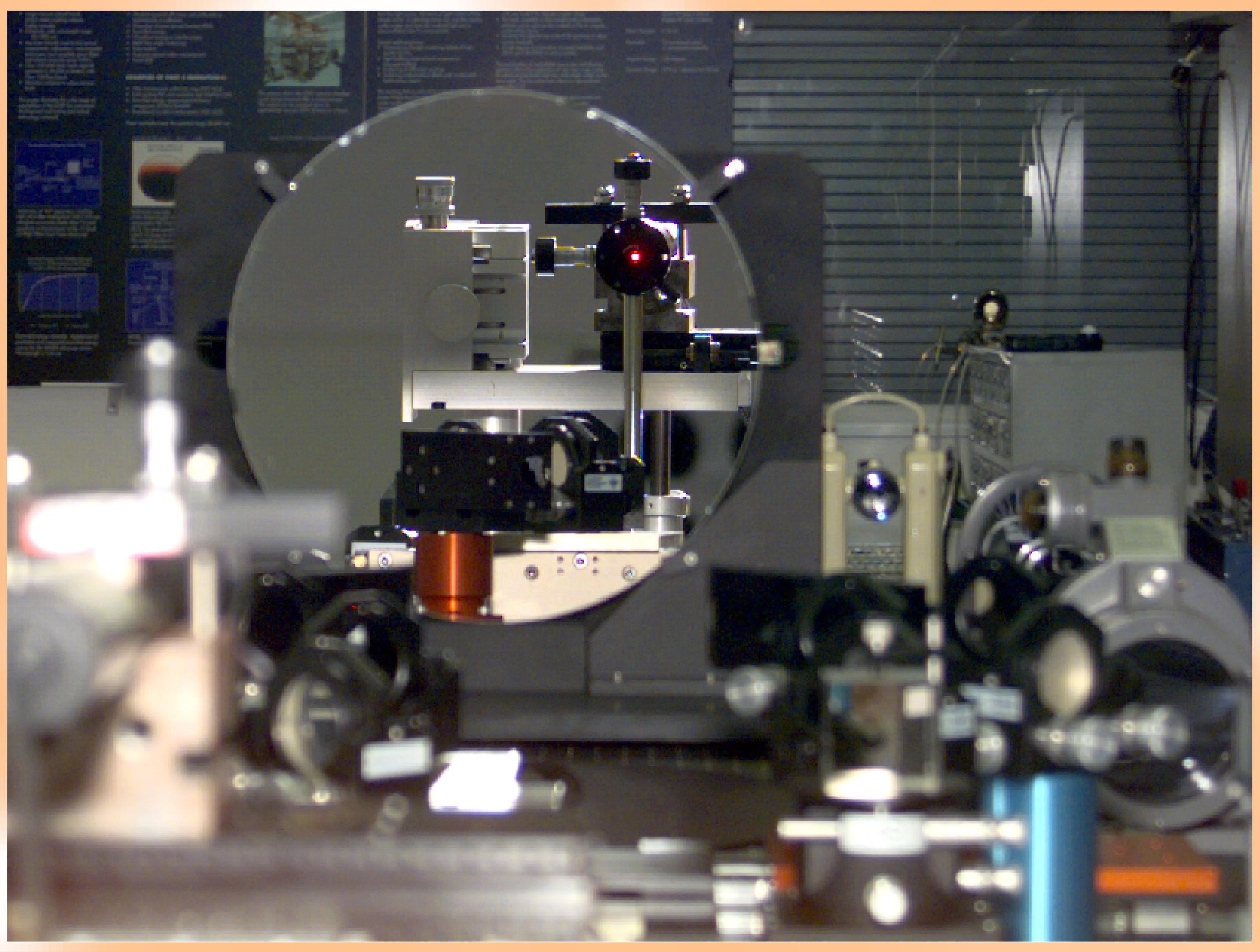

Figure . WIIT Testbed Assembly

S P E C S

Design

Figure shows the WIIT optics design schematically. A parabolic collimator produces parallel beams from a source located at its focus, simulating the "infinity" condition corresponding to a source on the sky. Two flat mirrors collect parcels of the collimated wavefront, and after beam size reduction by the beam reducer optical train and path length compensation by the cat's eye delay line, these pupil plane beams are combined through a beam splitter to produce two output beams. Each is further imaged by a dielectric lens before final detection at the focal plane of the imaging lens. The spatial frequency the so called u v plane is sampled by varying the baseline length using two linear translation stages that carry the collector mirrors, and varying the effective baseline orientation by rotating the source.

A CCD detector array is placed at the focal plane of the lens, with the focal length of the lens chosen to match the spacings of the CCD pixels such that the pixels Nyquist sample the primary beam of the collector mirrors. This arrangement will allow the interferometer images acquired by individual detector pixels to be "mosaiced" together during the data analysis process. It also allows the recovery of a portion of the low spatial frequency flux that is not directly measured by a single pixel interferometer. A single dish mode will be used to recover the remaining extended emission flux. The final linear resolution corresponds to the maximum baseline separation, and the number of resolution elements per image is given by the number of primary beams sampled by the CCD times the number of interferometry resolution elements per CCD pixel. For the actual WIIT design , this number is comparable to what is intended for SPECS, i.e. , linear resolution elements.

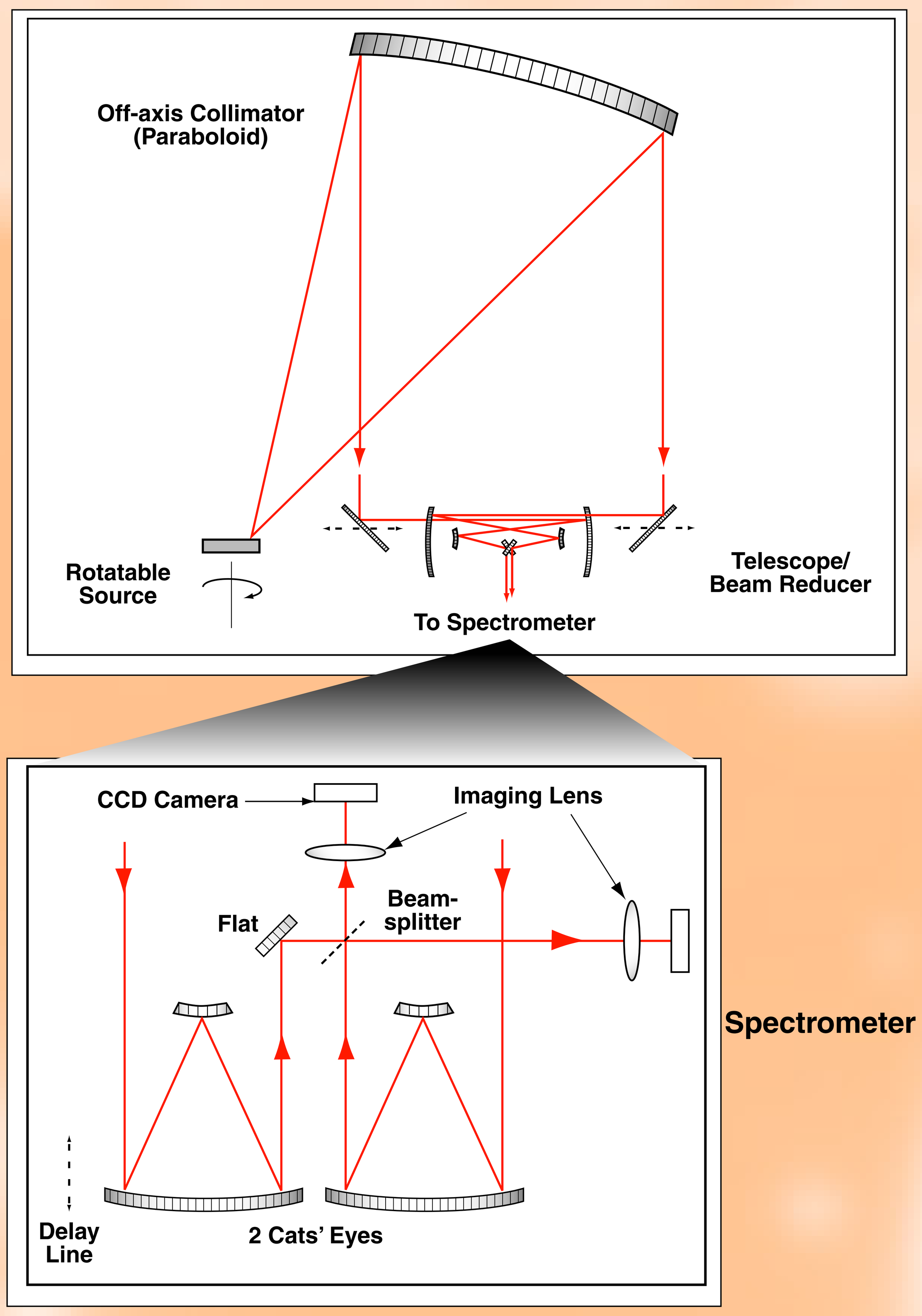

Figure . WIIT Optics Concept

In the design that is chosen, we have about inches of usable baseline and inch diameter collector mirrors. The focal length of the collimator paraboloid is about . meters. We will be using x x detector pixels, and each pixel is further resolved by the interferometer into - x sub pixels. The field of view ranges from to arcminutes. We intend to achieve a spectral resolution on the order of . The operating wavelength is about . µm. The mechanical tolerances of this optical wavelength testbed exceed that of the future infrared interferometers. The experience gained here will help us understand the corresponding requirements for the space instruments.

In Figure , we show an image of the WIIT testbed currently assembled at NASA's Goddard Space Flight Center. We have completed the initial alignment, obtained the first laser fringes, and are in the process of obtaining white light fringes and performing imaging interferometry.

ACKNOWLEDGMENTS

We thank Lee Feinberg, Mike Hagopian, Javier Lecha, Will Maynard, and the rest of the WIIT team for their contributions to the design and development of the testbed and preliminary work on the data acquisition, data analysis algorithms, and software.